

repaired. Other damage, such as small buildings demolished, occurred on the field. In other parts of the city telegraph poles, trees, small buildings, and roofs were either damaged or blown down, and a few people lost their lives by being hit by falling objects.

It is my belief in studying this storm and the available data in connection with other local and general winds in this area that moderately strong winds will generally flow over a mountain having gentle sloping sides, especially if the mountains is not very high, in much the same manner as the flow of air that moves over the cambered surface of an airplane wing, the result being reduced

pressure<sup>1</sup> and increased velocity of wind in lee of the highest point. In such cases, I believe that a high precipitous mountain will act as a barrier and the wind will not descend directly down the leeward side but reduced pressure will occur on the lee side as in the other case. When very high winds prevail, I believe that they will often descend the leeward side even of high precipitous mountains, but the flow will be variable and great turbulence prevail.

<sup>1</sup> Detailed airway weather maps for California at times showed peculiar pressure distributions which seemed to be out of harmony with the rest of the map. Mr. D. M. Little first drew these peculiarities to my attention and pointed out that it was due to the compressing of air on the windward slopes of mountains and the expansion on the leeward side as a result of the general wind flow over the region.

## THE GOTHENBURG, NEBR., TORNADOES JUNE 24, 1930

By ALFRED RUSSELL OLIVER

Tuesday evening, June 24, 1930, a series of tornadoes began in Lincoln County, Nebr., swept southeastward across Dawson County, and ended in Phelps County, leaving behind them a path of destruction 70 miles long and varying in widths from a quarter of a mile to 2 miles. (Fig. 1.) The storm was first observed about 3 p. m., struck its first blow about 5:30 p. m., and was over by 8 p. m.

The weather map for Tuesday morning, Figure 2, shows that almost the entire United States west of the Mississippi was covered by an area of low pressure. Over most of this area the variations in pressure did not exceed two-tenths of an inch, the extremes being 29.7 and 29.9 inches. Thus the barometric gradient over the

were rolling and tumbling and boiled upward as they came together. The new cloud continued southeastward about 14 miles toward Boxelder Canyon, becoming darker, more agitated, and continuously more threatening. Behind this cloud was the thunderstorm which brought the rain and hail, a not unusual condition under such circumstances.

The location of North Platte in the formative area of the tornado makes the weather observations there especially significant. In this connection it should be

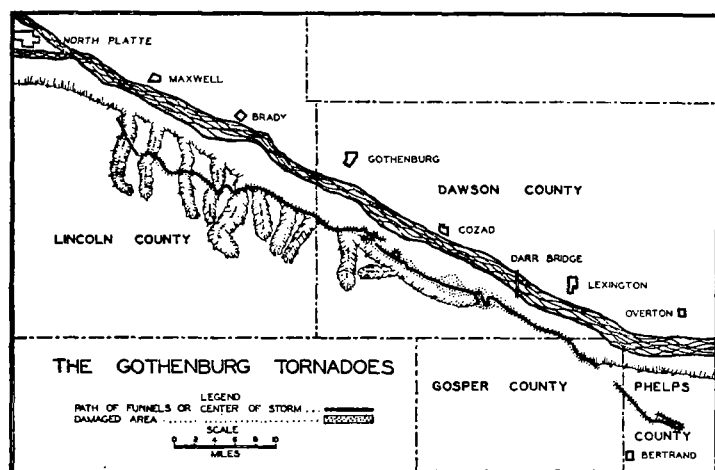


FIGURE 1

entire western part of the country was very slight. These conditions are typical of those which produce the common thunderstorm of this country. A high, with a pressure of 30.1 inches, was centered over western Oregon; another, with a pressure of 30 inches, existed over southern Louisiana. (See figs. 2 and 3.)

The tornadoes occurred between 5 p. m. and 8 p. m. In some cases coincident with them, but generally somewhat later, violent thunderstorms, accompanied by strong winds, occurred at several points in Nebraska, north, south, and east of the tornado belt, but there was no general storm over the State. That tornado conditions seem to have started developing west of North Platte is indicated by reports of violent agitation of the clouds 15 miles west of there. These clouds moved eastward along the Platte Valley. At North Platte two clouds appeared to unite, one coming from the west, the other seeming to materialize out of the air overhead. Both

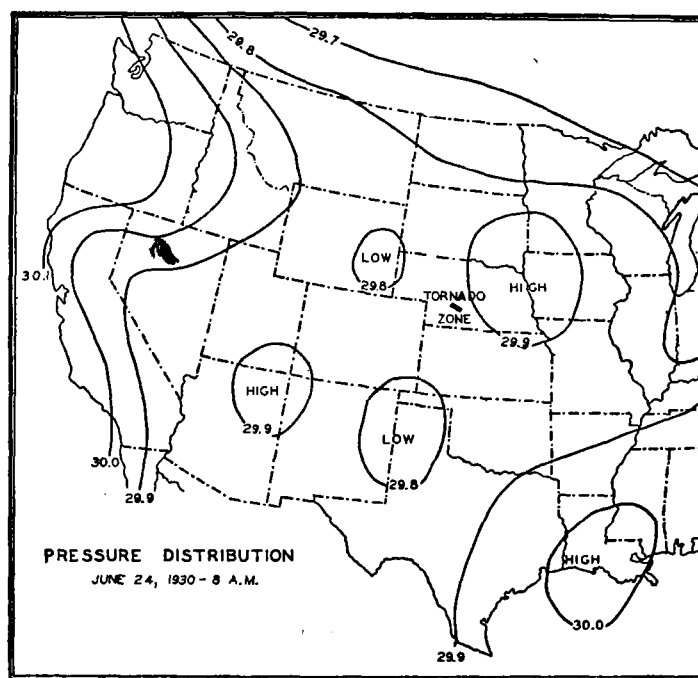


FIGURE 2

remembered that the storm was forming from 3 p. m. to 5:30 p. m. and was over by 8 p. m. A heavy thunderstorm prevailed at North Platte<sup>1</sup> from 3:55 p. m. to 5:45 p. m., with a rain lasting until 4:29 p. m., then a heavy hail for 15 minutes, and then rain again until 4:57 p. m. The rainfall for the afternoon was 0.32 inches. Hailstones 2 inches in diameter were picked up, consisting of from 75 to 100 ice pellets frozen together. A continuous roaring, as of trains passing through a tunnel, was heard before and after the rain and hail. The barometer fell steadily from 26.98 inches at noon to 26.85 inches at 7 p. m. The temperature dropped from

<sup>1</sup> Detailed information concerning conditions at North Platte was supplied by Mr. A. W. Schilling, junior meteorologist there.

86° at noon to 70° at 5 p. m., rose to 77° at 7 p. m., and then began the normal nightly decline. The humidity was slightly above normal at 7 a. m., and about 40 per cent above it at the noon and evening readings. The wind was moderate during the afternoon, but very changeable, as shown by the following table:

1:00 p. m.	—4:36 p. m.,	southeast.
4:36 p. m.	—4:37 p. m.,	south.
4:37 p. m.	—4:44 p. m.,	east.
4:44 p. m.	—4:45 p. m.,	north.
4:45 p. m.	—4:49 p. m.,	northwest.
4:49 p. m.	—5:00 p. m.,	west.
5:00 p. m.	—5:04 p. m.,	south.
5:04 p. m.	—	east.

The variable wind, the rapid drop in temperature, the steadily falling barometer, and the unusually high hu-

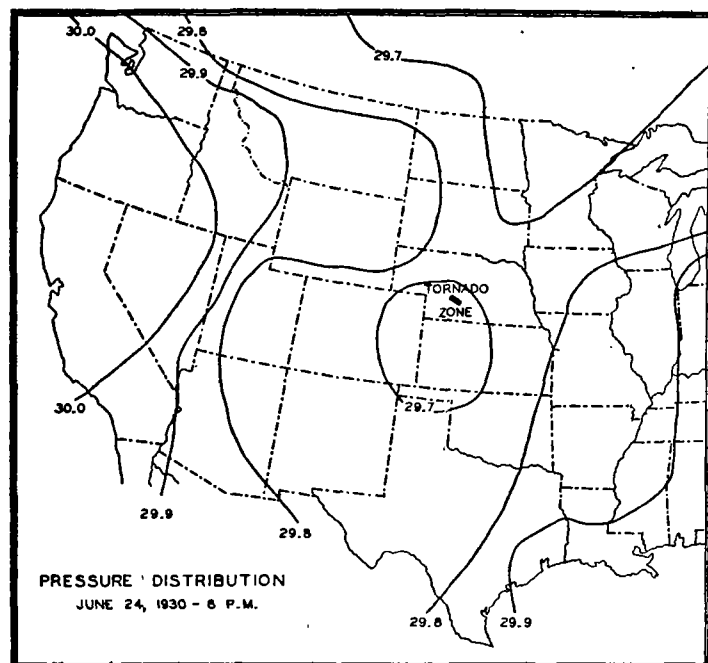


FIGURE 3

midity indicate very unstable atmospheric conditions. Observers noticed that while only a gentle breeze existed on the ground, the clouds at higher levels were carried in different directions, tossed and tumbled by strong conflicting currents.

The tornado began to assume definite form in the vicinity of Boxelder Canyon, the process being described by several observers. The afternoon was hot and sultry, with no wind for an hour before the tornado. The sky to the north and west was overcast by a huge black thundercloud which extended southward beyond the bluffs about 5 miles. Below this were two other layers of clouds. The upper layer, some distance above the ground, was white and traveling due north; the lower layer, close to the ground, appeared to be nearly black and traveling due south; both were moving at high speed. The two did not unite; but the lower layer, which was rolling and tumbling, eventually formed a typical thunderhead on the southeast corner of the main cloud, but lower and slightly in advance of it. This thunderhead, described by some as consisting of several layers, whirled rapidly counterclockwise, rolling and tumbling in all directions within the whirl. One observer said a southwest and a northeast wind seemed to meet head-on about this time and the clouds became still more agitated. Clouds were rushing into this center

from all sides. No funnel appeared, but the whole cloud settled close to the earth, and a column of dust about 2 rods wide rose to meet it. The two never united and the dust column soon collapsed. All this time a roar was heard overhead.

The storm traveled southeastward and struck its first blow at Cottonwood Canyon (Fig. 1) shortly after 5 p. m. Its course from Cottonwood to Jeffrey Canyons was a zigzag one. It apparently traveled south, northeast, east, and southeast through this part of its course. Observers some miles north reported that the funnel seemed to whip back and forth in a great arc which they estimated to be 5 miles wide, writhing and twisting like a snake. From Jeffrey Canyon it traveled due east to the valley edge, then turned southeast, following the bluffs to the mouth of Hiles Canyon.

Its path was narrow, never over half a mile wide, while the zone of greatest intensity was only a quarter of a mile wide. At Tree and Gulch Canyons the center was about 500 to 800 feet wide, widening again east of Tree Canyon. About 2 miles east of Gulch Canyon it lifted, passed over four farmsteads, and dropped straight down on Tree Canyon. As it lifted the funnel broke into two parts,

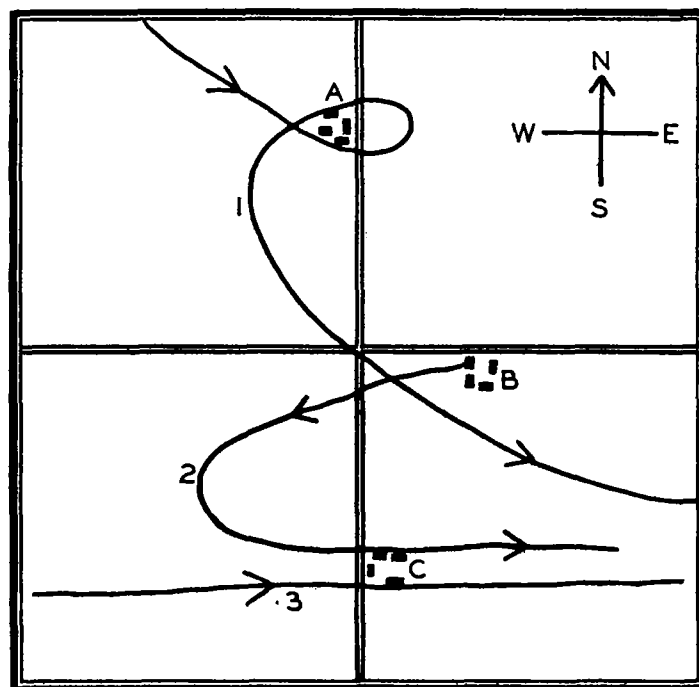


FIGURE 4.—Detail of tornado paths near McDowell farm southwest of Cozad

both whirling independently, the lower finally settling. The upper part gradually lifted and lagged behind until it was pointing due west, parallel to the surface of the cloud above, writhing and twisting. After rising the funnel was white, which seems to have been its usual color when not in contact with the earth. While up in the air no roar was heard and there was no wind on the ground. Mr. Quinn, at Tree Canyon, stood at the cellar door watching the storm approach and thought it was passing over. He estimated the funnel to be 400 feet above the ground. Suddenly the tail began to curl down, and when it struck the ground 300 feet west he jumped into the cellar. The storm lasted only a few seconds there, but he said it sounded like the battlefields of France. At Jeffrey Canyon Mr. Sytsma said it lasted four minutes. It struck Tree Canyon about 6 p. m.

Observers commented on the number of funnels formed, three or four of which were visible at a time.



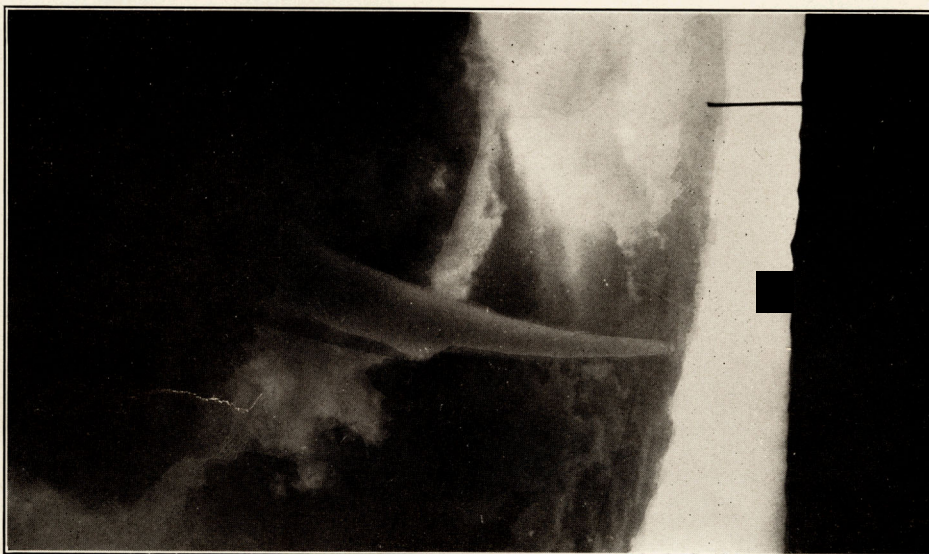


FIGURE 5.—Distribution of wreckage at the Quinn ranch at the mouth of Tree Canyon, about 6 miles southwest of Gothenburg



FIGURE 6.—Funnel approaching Quinn ranch at Tree Canyon. View taken by Mrs. Ray Homer from a point one-half mile east of the funnel

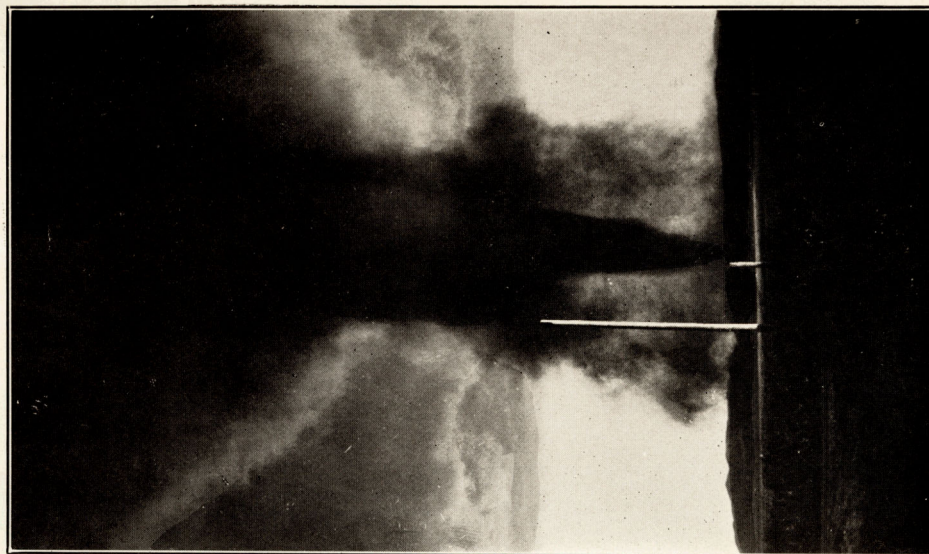


FIGURE 7.—Funnel at the moment of striking the Quinn ranch. Photograph by Mrs. Homer



Over a dozen funnels formed and dropped, but never reached the ground.

From Hiles Canyon the storm traveled east about 2½ miles, leaving the bluffs and moving out into the valley bottom. From this point almost to the end it moved in a southeasterly direction, staying in the valley until it reached a point due south of Lexington. There it passed up over the bluffs to the uplands, where it finished its course. The path varied in width from 1 to 2 miles, narrowing and widening until due south of Darr Bridge. The funnel rose and fell, being high enough much of the time to hit only the taller structures and trees. Due south of Darr Bridge its path narrowed quickly to a width of half a mile, and this was its maximum width for the remainder of its course.

For 2 miles due east of Hiles Canyon it was up in the air, hitting only the higher structures. Then it jumped due south a half mile, missing everything. At this point it dropped to the earth and moved east for 2 miles, wiping out nearly everything in its path. The funnel then jumped 1 mile southwest, doing little damage, but settling at that point to destroy one place.

During this part of its course the cloud continued to drop numerous funnels, some of which reached the ground. Observers testified that a funnel would drop, move due east 1 or 2 miles, and break up; then another funnel a half mile or a mile south or slightly southwest would form and repeat the performance. This story was supported by the lines of wreckage in the field which lay in a due east-west direction, sometimes overlapping a little and always paralleling each other, with little or no damage anywhere on the southward jumps. The path of the storm was in a southeasterly direction, but the lines of wreckage extended east and west.

According to observers, three funnels were in operation at almost the same time a mile north of the mouth of Midway Canyon. The wreckage seemed to support the story. The diagram, Figure 4, illustrates their movements.<sup>1</sup> Funnel 1 came from the northwest, passed over farmstead A, circled a few hundred feet east and came back over it, then turned and moved southeast over a cornfield between B and C. Funnel 2 dropped directly on B, traveled southwest a few hundred feet, and circled to the southeast, striking the north edge of C. Funnel 3 started dropping about 1 mile west of C, over which it passed, but high enough in the air so that it caught only the highest points at C. It hit the ground 100 feet east of the barn and destroyed a strip through a wheat field. The paths were all narrow, and funnels 2 and 3 disappeared about 1 mile east of C. The funnel circled in a similar manner at two other places, and three funnels struck at one other place.

From here the storm continued to the southeast, the path narrowing and the funnel striking the ground only here and there. Due south of Cozad the path widened again, but the point of the funnel remained high enough in the air to hit only the highest objects. South of Darr Bridge the storm became more intense, narrowed to a width of half a mile, and the funnel extended to the ground, destroying nearly everything in its path until it reached the bluffs of the Platte Valley.

As the storm moved across Gosper County it was joined by a cloud from the east and one from the southeast. Another funnel dropped, striking the ground near the Phelps County line, but did no damage west of the

line. In Phelps County the storm was as concentrated and violent as in its earliest stages. It moved to the southeast over a path not more than half a mile wide, wiping out several farmsteads. The funnel never left the ground until it finally broke. About 6 miles north-east of Bertrand the funnel, traveling due east, passed over a farmstead. A quarter of a mile east of the farmstead the funnel made a half-circle turn to the left and came back over the same farmstead, moving due west. After passing the farmstead the second time it moved northwest about a mile and a half into a pasture, where it broke up. In both pastures the grass was scoured and beaten, much of it killed, and debris scattered around. It retained its violence to the last, completely wrecking a strongly anchored fence, where it disappeared.

At the end the funnel dipped and rose three or four times, the last time apparently breaking into two parts about halfway up. The lower half continued to whirl a short time and then, according to the account of witnesses, apparently exploded. The upper half lifted into the cloud and the storm was over, about 8 p. m.

The forward movement of the storm was slow. It traveled about 70 miles in approximately 2 hours and 45 minutes, giving it an average speed of about 25 miles per hour. Observers estimated its speed at 20 miles an hour. The rate of movement varied in different parts of its course. It traveled from Boxelder Canyon to Hiles Canyon, a distance of 24 miles, in one hour. It moved most rapidly during the middle part of its course, from Hiles Canyon to the bluffs, a distance of 28 miles, which it traversed in 45 minutes. Then it slowed down, traveling the last 16 miles in about one hour, the funnel striking the ground only during the last 10 miles.

Observers disagreed as to the direction of the wind before and after the storm. The majority of those questioned gave the direction as east or southeast before and west or northwest after the storm. All agreed that the wind was gentle before the storm, very strong for about 20 minutes after, and then gentle again. There was little or no rain before the tornado. The rain afterwards ranged from light to heavy, always with a sprinkling of large hailstones of the same type that fell at North Platte, and did not last over half an hour. The rest of the evening was unusually pleasant.

Except where it circled and struck twice, wreckage was distributed as would be expected. On the right, or south, side it was thrown to the east or northeast, forward and into the storm. On the left, or north, side it was thrown to the west and southwest, backward and into the storm. Wreckage that was carried any distance was carried to the east, usually not over half a mile. Trees and buildings were twisted counterclockwise. One barn was picked up, turned almost around, and, badly shattered, dropped in place. Buildings and posts were plastered with mud on the south and west sides, especially the south. The only exception to this was where the storm circled a place, and here the east face was plastered with mud. The mud was generally half an inch thick.

Examples of explosive action in the center of the storm were frequent. Windows were blown outward, in some instances disappearing without leaving a trace. In several buildings the walls, almost intact, blew outward and the roof dropped on the floor. In some cases roofs were partially or wholly removed, the walls remaining in place but bulged outward. Doors to caves were wrenched open outward. In one case the people reported difficulty in remaining in the cave due to the storm's suction.

<sup>1</sup> It was about 10 to 12 days after the storm before the writer reached the point where the 3 funnels described struck. The entire area covered by the funnels, with the exception of the farmsteads, was cornfield. As it had been cultivated since the storm, it was practically impossible to trace the paths of the storm in the field. The story is based on the account of 6 or 7 observers, some of whom were in the storm area and some a short distance to the side. All told the same story. They also pointed out the paths as given in the diagram, and a little wreckage was found, which seemed to substantiate the story.

At Conroy Canyon there is a cement-lined cistern, sunk level with the ground and covered with a loose board top. It is 16 feet long, 8 feet wide, and 8 feet deep, and before the storm had 4 feet of water in it. According to Mr. Ginapp, the center of the storm passed over it, removed half the top, and sucked out every drop of water. A lake with a surface area of 4 acres is located at the mouth of Tree Canyon, and out of this lake according to the testimony of a Mr. Quinn, who lives nearby, 2 feet of water disappeared.

Examples of scouring were found throughout the course of the tornado. In cornfields lister ridges 8 to 12 inches high were leveled. The best example of scouring was seen at Gulch Canyon. Before the storm all slopes were covered with a heavy growth of grass and low shrubs. Wherever the center struck, grass and shrubs were torn out by the roots, leaving the earth bare. In places even the earth was gouged out. Around this area everything was beaten down as if by a muddy torrent. The transition from this beaten zone to the

At one place a big truck was carried 300 feet up a hillside and destroyed. The tires, which carried 80 pounds pressure, were not punctured; but blades of grass were driven between tires and rims. The heaviest iron machinery was so twisted as to be made useless. A cement watering tank, 16 feet across and 2 feet high, was broken in half. One half was moved 20 feet eastward and shattered; the other, intact, was moved 10 feet; but a bag of feathers hanging by an ordinary string from a tree beside the tank was untouched. Brick and cement foundations only 2 feet high and set in the ground 6 inches were shattered. Two concrete blocks, weighing about 2,000 pounds each, were torn from their fastenings and rolled several feet. A combine was rolled and pushed a quarter of a mile and wrecked.

On one farm stood a garage in which the farmer kept his car and a 16-jar Delco light plant. A neighbor drove over to use his cave and parked his car beside the garage. The storm struck and the garage disappeared. The car in the garage suffered no damage except a broken wind shield, while the car outside was destroyed. The home from which the neighbor had fled was untouched. Mr. Sytsma said that 4 glass jars of the battery for the light plant were broken; the other 12 were taken from the shelf, 5 feet up, and placed on the cement floor without cracking any, but 3 were overturned so that the water escaped.

There were several places where almost every move of the center of the storm could be traced, but one of the best was about 4 miles northwest of the mouth of Midway Canyon. At this point stood a farmstead with several fine buildings and large feed yards surrounded by trees, the whole about a quarter of a mile square. The center of the storm passed over it and extended little, if any, beyond the trees. On the east side the trees were left pointing to the east and northeast, on the north to the north and northwest, on the west to the west and southwest, and on the south to the east and northeast. Toward the center they pointed in all directions, but plainly showed a counterclockwise twist. The buildings in the center were completely wrecked and the wreckage scattered to the east.

The Quinn ranch, at the mouth of Tree Canyon, also offered an excellent opportunity to study the movements of the air currents in the center of the storm. The farmyard is about 1,000 feet long from northeast to southwest. The funnel crossed it at right angles and was about 500 feet wide at this point. The north and south ends of the yards were not damaged, while the central portion was destroyed. Figure 5 shows the lines on which the wreckage was distributed by the storm. All wreckage not dropped in the yard was carried eastward for distances not exceeding half a mile. Wreckage from the house was scattered in three directions. The chimney was thrown to the north, the walls, roof, and most of the furniture were carried along a curved line to the northwest, while the floor was carried eastward. Some of the furniture on the floor dropped into the basement. Twenty-two tons of baled hay in the barn were carried eastward, while the rest of the wreckage was scattered along the curved line to the southeast. The wreckage of the feed house was found 1,000 feet to the east. The path of the wreckage from the chicken house was not determined.

Trees varied noticeably in their ability to withstand the storm. Cottonwoods were damaged the most, while pines and cedars suffered the least.

The damage done by the storm was estimated at about \$200,000, which no doubt was moderate, as there were several farms where the loss ranged from \$10,000 to

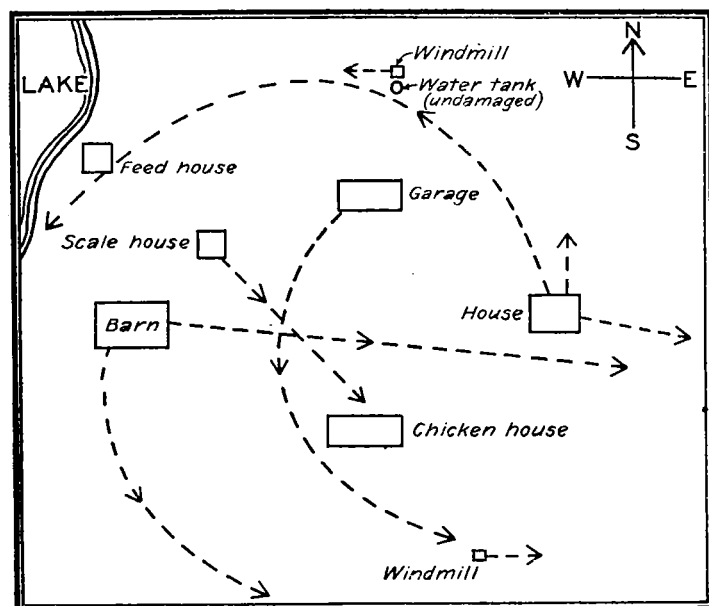


FIGURE 8.—Funnel a few seconds after striking Quinn ranch. The outer, lighter part is believed to consist of debris, dust, and water. Photograph by Mrs. Homer

undamaged zone was abrupt, taking place in a 2-foot strip. There was no leeward, protected slope. It swept up the west slope and down the east without missing an inch, no matter how sharp the crest. Pockets barely big enough to hold a man's body were thoroughly scoured out. Grass, looking as if a muddy torrent had rushed over it, was common throughout the storm area.

The center of the storm passed over an orchard of trees not over 10 feet high and stripped off every leaf and twig, but did not uproot, twist, or break a tree. Similar cases were common. In wheat fields the heads were frequently stripped off and the stem left standing.

Due south of Cozad the funnel passed over the farm of a Mr. Derrickson, destroying the upper part of the barn and the tops of trees and the windmill, but doing no damage to anything less than 30 feet above the ground. Mr. Derrickson was in the barn when the storm struck it. He felt the barn jump, stepped out into the yard, and walked 100 feet to the house, under the funnel which was about 30 feet above him. He said there was no noticeable wind in the yard, not even enough to stir the dust. Overhead it was black as night, and he could only see about 30 feet upward because of the dust and cloud of the funnel.

\$20,000. Only one life was lost and five people injured. The low loss in life and property was due to three causes. The storm struck only rural sections throughout its course. It moved slowly, about 20 miles an hour, making it easy to get out of danger. It was visible for miles, and nearly everyone had watched it for at least 15 minutes before it struck. Word was also sent in advance by telephone.

The storm seems to have been due to conditions in the upper atmosphere, rather than unequal or extreme heating of the earth's surface. A check of the pressures, temperatures, and wind velocities reported from the stations surrounding North Platte revealed only slight differences. There was no hot wave before the storm; in fact,

the week preceding had been rather cool. Strong contrary winds were observed tossing the clouds at different levels before there was any sign of a tornado, while it was nearly calm at the ground. One observer said that it seemed to him as if a southwest and a northeast wind had met head-on overhead and started a whirl which began to enlarge and suck the clouds in toward it. The large number of funnels formed would indicate that a number of eddies existed in the upper atmosphere, but not all had strength enough to reach the ground. Some observers said that the tornado cloud seemed to consist of several layers at first. The make-up of the hailstones would indicate the presence of several levels of air with different temperatures.

## HAIL DAMAGE IN IOWA

By CHARLES D. REED

[Weather Bureau, Des Moines, Iowa]

Assessors in Iowa are required to ask each farmer on about 210,000 farms as to the amount of hail damage to crops on his farm the preceding crop season. These data are tabulated and summarized by the weather and crop bureau of the Iowa Department of Agriculture.

Eight years of these data are available at the close of 1930. In that period the average annual hail loss in the State was \$4,513,760, while the average value of the crops at risk was \$391,483,456. The greatest loss, \$7,975,686, was in 1925, and most of it occurred in the storm of August 18, extending from the southeast corner of Poweshiek and the southwest corner of Iowa Counties, almost due southeastward about 60 miles across Keokuk, Washington, Jefferson, and Henry Counties and into Lee County. The total damage in this storm was approximately \$5,000,000, making it probably the most destructive in the history of the State. The least damage was \$1,598,963 in 1930.

The greatest county damage was \$1,076,280 in Woodbury County in 1929, and the greatest township damage was \$321,380 in Liberty Township, Keokuk County, in 1924. The average number of townships reporting hail damage in the past eight years is 563, or 35 per cent of the total number of townships. In 1929, only 387 townships, or 24.1 per cent, reported hail, which is the least in the eight years, but the damage in these townships was rather intense, so the total was greater than in 1930.

Data are insufficient to work out definite zones of damage, but it now appears that the counties along the Missouri and Big Sioux Rivers and those adjacent are more subject to hail than other portions of the State, while a good many counties in southeast Iowa, particularly Davis, are nearly immune. In the 8 years, 24 counties had one or more years with no damage; 14, mostly in the southeast, had only 1; 4 counties, Dallas, Henry, Louisa, and Monroe, had 2 years; 5 counties, Des Moines, Jefferson, Lee, Van Buren, and Wayne, had 3 years; and 1 county, Davis, had 4 years without hail damage.

In the eight years, 159 townships, or about 10 per cent of the area of the State, reported no hail. It was found that in several cases considerable damage was reported by monthly crop reporters and others in some of these 159 townships from which the assessors reported no

damage. This discrepancy may be explained by the fact that crop reporters make their reports immediately after the storms occur, and at certain stages crops, especially corn, in a favorable season, have been known to largely recover from what at first appeared to be almost total destruction. Some months later when the assessor visits the farmer, the crop harvested is so nearly normal in yield that the farmer has forgotten all about the damage.

On the other hand, hail damage is so extremely localized, being large on one farm and amounting to nothing on an adjoining farm, that the actual acreage that escaped damage in the eight years is no doubt greater than the 10 per cent shown by using the township as a unit, and may be twice that amount.

It is recognized that the fluctuating values of crops of nearly equal quantity, or the inflation and deflation of the dollar, makes the dollar an unsatisfactory unit for measuring and comparing hail damage over a long period of years; yet it is convenient; a more complicated method might break down the cooperation of assessors and farmers; and eventually refinement may be effected by applying some commercial index number. The per cent of damage requires no such refinement. It is found by dividing the total damage (times 100) by the total value of crops at risk. In this 8-year period it averaged 1.15 per cent, the greatest being 1.99 per cent in 1925 and the least 0.50 per cent in 1930.

Further details are shown in the accompanying table.

Experience of hail insurance companies shows a larger per cent of damage than these figures indicate, for the reason that it is easy to write policies in a territory where devastating hail storms are of almost annual frequency, and relatively hard to write policies in a county like Davis, where damage is rare. The rates of the companies must therefore be basicaly higher and must, in addition, include the cost of getting the business, adjusting the losses, setting up reserves, maintaining offices and employees, and general overhead expenses.

If this line of inquiry is continued long enough, possibly when 20 years of data are available, a more satisfactory scale of county or even township rates for hail insurance may be worked out.